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Comparative Degenerative Joint Disease of the Vertebral Column in the Medieval Monastic Cemetery of the Gilbertine Priory of St. Andrew, Fishergate, York, England

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ABSTRACT The pattern of degenerative joint disease (DJD) of the intervertebral and apophyseal joints of the vertebral column of 81 skeletons from the thirteenth to fourteenth century medieval priory cemetery of St. Andrew, Fishergate, York, was recorded in relation to their location of interment: eastern cemetery, southern cemetery, and intramurally (within the priory buildings). Archaeological context and ethnohistorical accounts support the interpretation that people of different social status were buried in these areas. Linear discriminant function analysis and paired Kolmogorov-Smirnov tests showed that the differences in vertebral column DJD pattern and severity among the three subgroups were not statistically significant. As the archaeological and historical evidence seems reliable, it is argued that the analysis of DJD of the vertebral column might not be ideal to study the effects of normal activity patterns, a conclusion which supports the results of recent bioarchaeological research. Further, high-low plots demonstrate that the differences in DJD pattern were located between intervertebral and apophyseal joints of individuals rather than between subgroups of the cemetery. It is thought that this difference was produced as a response to erect posture during bipedal locomotion, reflecting vertebral curvatures, rather than differing occupational stresses. Thus, due to biological constraints on its function, the vertebral column might not be an ideal structure to study markers of occupational stress. Am J Phys Anthropol 103:481–495, 1997.

Although the possibility of a relationship between occupational stress and the pattern and severity of degenerative joint disease (DJD) has been repeatedly suggested, recent research has suggested that DJD as a direct indicator of habitual activities cannot be sustained (Bridges, 1991, 1994; Jurmain, 1990; Lovell, 1994). This is at least partly due to the realization that DJD is an age-related phenomenon (Rogers et al., 1987; Waldron 1991, 1992) and other factors such as sex, ancestry, weight, and movement have a role in its etiology (Waldron, 1994). Research on the relationship among biomechanics, functional stress, and DJD has shown that the presumed clear association between DJD and activity cannot easily be demonstrated from medical or bioarchaeological populations. Studies of habitual athletes, however, appear to present the most conclusive results supporting an association between habitual physical activity and no increase in osteoarthritis (Lane et al., 1986; Panush et al., 1986; Williams et al., 1984). The present study contributes a consider-

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ation of the complex relationship between DJD and habitual activity in a medieval European population.

The pattern of DJD of the intervertebral and apophyseal joints of the vertebral column of 81 skeletons of the medieval monastic cemetery of Fishergate, York, England, were recorded and analyzed. The burials chosen belonged to the period from the early thirteenth to the early fourteenth century (periods 6a, 6b, 6c, 6z, defined by changes that were undertaken in the architecture of the priory buildings) and were a part of the cemetery of the Priory of St. Andrew of the Order of St. Gilbert of Sempringham (Stroud and Kemp, 1993).

The skeletons were excavated from three areas of the cemetery: east and south of the priory buildings and intramurally. Archaeological as well as historical, osteological, and paleopathological data support the theory that socioeconomic status, occupation, life-style, and age category influenced the place of burial (Stroud and Kemp, 1993; Graham, 1901; Ariès, 1982). The eastern cemetery is thought to be the burial ground for the resident canons (ecclesiastics), the southern cemetery appears to have sheltered the workforce employed by the priory (the lay brethren), and the intramural area served as the burial ground for lay individuals and canons of comparatively higher status or distinction. Two groups of comparative interest are the presumed canons (eastern cemetery) and those that likely made up the workforce (southern cemetery). The third group (interred intramurally) acts as a control in that they are of high but nonecclesiastical status.

The differing life-styles of these three groups, reflected in differing activity patterns, can be summarized as follows. The Gilbertine canons themselves are known for their law-related activities, such as the copying and drafting of documents (Graham, 1901). It is known that they followed the Rule of St. Augustine, which commended study and intellectual pursuits in place of manual labour (Lawrence, 1992), thus leading to a rather sedentary life-style. The Gilbertine Order extensively employed a lay workforce for several domestic activities (e.g., agriculture, animal husbandry, gardening, carpentry, building maintenance) (Graham, 1901), who would have led a physically active life-style and would have been given the opportunity to be buried in the priory's cemetery. Others, too, would have preferred burial within the cemetery, including priests, wealthy patrons, benefactors, and those of well-to-do classes in exchange for bequests to the associated church or monastic establishment (cf. control group) (Ariès, 1982). This documented variation in life-style among the three named subgroups is supported by the differential presence of spondylolysis (more prevalent in the southern group), caries (more prevalent in the intramural group), diffuse idiopathic skeletal hyperostosis (DISH) (more prevalent in the eastern and intramural group), tuberculosis (more prevalent in the southern group), and fractures (equal across all three areas, but lower limb fractures were less prevalent in the eastern group) in the three cemetery areas (Stroud and Kemp, 1993). Consequently, the proposed canons, the workforce, and the higher status (intramural) lay persons, being representative of different occupations, socioeconomic status, and life-style, are expected to show different patterns of DJD of the vertebral column.

These three groups are reflected in the skeletal sample as follows. Adult males, more commonly in the older age at death categories, predominated in the eastern cemetery and priory buildings, while the priory church proper and the southern cemetery provided burial for both males and females of relatively more widely distributed age at death categories (Stroud and Kemp, 1993).

MATERIALS AND METHODS

The vertebral columns of a representative sample of 81 adult males assessed to be over 20 years of age at death were examined (37 from the eastern area (presumed canons), 21 from the southern area (lay individuals), and 23 buried intramurally [high status individuals] (Göggel, 1994). Since the eastern cemetery consisted of almost exclusively males with 90.9% (40 of 44) of them being older than 30 and 65.9% (29 of 44) being older than 40 (Stroud and Kemp, 1993: 173), only adult males of an age at death as similar as possible (see Table 1 for the age at death distribution of the 81 individuals stud-

TABLE 1. Age at death for the three subgroups of the cemetery

Age groups (years)	Eastern burial area	Southern burial area	Intramural burial area
20–30	3	4	3
30–40	10	7	4
40–50	12	8	9
50+	11	1	6
Adult	1	1	1
Total	37	21	23

ied) were selected from the other two areas, based on the completeness of the vertebral columns. Paired Kolmogorov-Smirnov tests between the age distributions of the three areas yielded a maximum cumulative difference between the southern and eastern groups of 0.23. This figure was smaller than the critical value of 1.36. Thus, there appears to be no statistically valid reason for assuming that age-related change has affected the distribution and severity of DJD.

A comparative analysis of the pattern and severity of osteoarthrosis of the apophyseal joints and of osteochondrosis and osteophytosis (marginal bone proliferation or *spondylosis deformans*) of the intervertebral joints was made of the three burial areas. The joint surfaces on the ribs and the costal facets were not considered in the present study due to incompleteness. DISH was also considered a degenerative process of the vertebral column (Resnick et al., 1975; Resnick, 1985; Resnick and Niwayama, 1976, 1988; Rothschild, 1988).

The following pathological lesions were recorded: osteophytes (OP), joint surface contour change (JSCC), porosity (PO), cyst porosity (CPO), sclerosis (SCL), eburnation (EB), and Schmorl's nodes (SN). The flowing ossifications of the anterior longitudinal ligament of DISH were recorded as severe osteophytes. The presence and severity of the lesions were recorded as 0, 1, and 2. The value 0 signified that no lesions were present, value 1 that the lesion was present but not severe, and value 2 that the lesion was present and severe. The grading system applied for all the joint surfaces (i.e., intervertebral and apophyseal joints) and was derived from the grading parameters, both visual and descriptive, used by Resnick and Niwayama (1988) and by Sager (1969).

Osteophytosis was recorded as a proportion of the articular surface width, thus adjusting for changing joint surface size. When the OP was smaller than a third of the joint surface width in large joints and smaller than half the width of it for small joints (e.g., apophyseal joints) and less than 50% of the circumference of the margin affected, a 1 was scored. If in excess of these values, the lesion was recorded as a 2. Since OP and JSCC are related phenomena, they were recorded as complementary. In cases of fused joints, the value for OP and JSCC was doubled, and in the cases of initial ossification of the intervertebral disc the value for SCL was doubled. This was done because these pathological conditions are considered to be extremely severe (Resnick and Niwayama, 1988).

Porosity and CPO are related phenomena, but the former occurs with relation to hyaline cartilage degeneration, while the latter seems to be more a consequence of disc degeneration (Resnick and Niwayama, 1988; Sager, 1969). Both were recorded as 1 when less than 50% of the articular surface was affected and as 2 when more than 50% of the joint surface was affected. Porosity was recorded as either small and superficial pitting or relatively bigger and deeper pores. Cyst porosity, on the other hand, appeared in the form of relatively large, deep, isolated cysts, occasionally showing sclerotic margins.

Sclerosis and EB are related phenomena in that EB never occurs without previous SCL, but SCL may occur without subsequent EB (Rogers et al., 1987). Sclerosis is a proliferative reaction in the subchondral bone forming localized or generalized thin or thick bone layers as a reaction to articular cartilage destruction. In the present study, any type of nonmarginal new bone formation on the joint surface (e.g., central OP) was considered as SCL. Sclerosis was recorded as 1 when it covered less than 50% of the joint surface and also when it appeared either as a thin layer of bone not associated with EB or as a small, uneven, localized lump of bone on the joint surface. Sclerosis was noted as 2 when it affected more than 50% of the joint surface and when it appeared as a thick, irregular, proliferating new bone formation. Sclerosis noted as 2

TABLE 2. DJD severity at the intervertebral joints: Added scores

Burial area	Burial number	OCC/C1	C1/2	C2/3	C3/4	C4/5	C5/6	C6/7	C7/8	T1/2	T2/3	T3/4	T4/5	T5/6	T6/7	T7/8	T8/9	T9/10	T10/11	T11/12	T12/L1	L1/2	L2/3	L3/4	L4/5	L5/S1
Eastern	1	1	4	15	14	18	6	3	29	3	0	2	2	2	6	21	21	3	4	10	8	10	6	8	8	4
Eastern	2	3	10	4	10	20	9	6	8	13	3	14	10	9	6	12	10	6	5	5	4	2	5	9	8	13
Eastern	3	7	8	5	7	10	9	8	2	4	7	6	8	7	2	2	8	8	9	8	8	9	10	0	2	5
Eastern	4	7	3	6	8	5	6	4	4	4	2	3	2	2	3	3	2	2	4	7	3	7	7	4	4	9
Eastern	5	6	4	8	2	6	4	4	4	2	3	3	4	3	2	4	1	4	6	5	5	2	3	6	11	7
Eastern	6	10	4	12	27	12	5	7	21	9	24	17	15	12	5	12	2	6	4	6	0	2	0	9	9	19
Eastern	7	3	4	7	4	4	5	5	7	4	7	4	14	6	10	27	25	12	25	6	4	2	3	34	10	4
Eastern	8	7	7	10	11	11	8	8	10	3	1	6	8	18	3	8	6	2	7	10	11	8	6	11	13	12
Eastern	9	2	4	11	11	11	8	6	10	8	6	8	7	8	6	11	10	4	16	11	10	5	8	7	11	9
Eastern	10	7	7	10	12	11	8	9	11	7	6	7	14	13	10	9	10	8	6	9	8	10	14	10	21	24
Eastern	11	8	8	25	30	23	14	11	11	5	5	6	9	12	7	7	9	29	24	9	6	6	12	9	13	9
Eastern	12	7	7	11	11	10	8	8	12	7	6	6	8	6	6	7	7	8	9	4	9	11	24	10	15	18
Eastern	13	9	12	12	8	8	8	10	13	7	6	10	12	7	11	10	6	7	6	8	11	9	12	11	16	10
Eastern	14	8	8	6	7	10	6	10	10	6	14	8	8	6	6	6	7	8	12	14	11	15	12	11	14	11
Eastern	15	8	13	14	12	14	10	2	11	9	10	7	6	5	5	9	9	10	6	8	6	9	9	13	29	10
Eastern	16	10	7	7	12	9	11	6	9	4	4	6	5	5	7	5	3	5	7	9	7	8	10	10	13	9
Eastern	17	7	6	10	11	11	9	9	12	7	7	7	8	7	6	7	8	8	8	10	12	8	10	11	19	14
Eastern	18	7	4	10	12	11	8	8	11	7	6	0	4	6	7	7	4	7	8	22	10	13	17	15	20	24
Eastern	19	5	6	8	4	6	5	2	9	10	4	7	3	4	4	3	2	6	13	14	8	10	10	11	13	14
Eastern	20	6	4	14	8	4	8	4	6	8	2	4	3	6	2	4	8	8	8	9	11	10	14	10	9	12
Eastern	21	6	7	11	11	11	8	6	15	10	4	5	5	9	7	3	9	12	13	7	6	8	7	9	8	9
Eastern	22	7	7	10	11	10	9	9	12	7	6	6	8	1	4	7	7	27	12	9	8	8	15	16	20	13
Eastern	23	7	7	11	12	11	8	8	12	7	7	7	8	6	6	6	7	8	9	6	14	13	15	6	14	7
Eastern	24	7	6	10	11	11	6	6	12	17	15	6	6	4	4	23	33	18	10	14	14	13	14	12	10	16
Eastern	25	10	7	11	12	15	5	7	18	10	4	6	6	9	2	4	5	11	10	10	5	6	13	12	28	15
Eastern	26	6	9	26	28	24	8	9	18	2	3	7	5	6	5	8	5	11	5	4	10	16	10	11	14	11
Eastern	27	9	6	2	4	4	3	0	0	0	5	3	1	0	8	4	3	3	10	9	5	6	8	9	11	14
Eastern	28	8	7	8	13	11	4	6	4	4	4	7	8	6	6	7	7	8	8	9	11	10	11	10	10	17
Eastern	29	12	10	10	13	14	13	14	23	10	9	5	9	13	5	9	8	2	8	5	12	12	14	12	12	12
Eastern	30	4	5	7	11	11	10	8	13	12	10	10	2	3	9	9	5	11	12	10	5	6	10	10	12	12
Eastern	31	7	7	10	11	11	6	5	12	9	6	7	14	7	4	2	9	2	6	5	8	8	8	8	10	8
Eastern	32	8	8	11	14	9	7	7	16	7	9	4	5	13	3	2	2	1	7	9	6	11	8	13	14	6
Eastern	33	10	6	12	8	25	13	14	14	6	9	10	7	7	7	10	5	8	7	10	7	11	9	11	16	12
Eastern	34	9	5	8	10	9	8	18	22	4	2	5	4	4	1	4	4	8	8	8	12	9	12	12	9	7
Eastern	35	14	8	11	12	10	8	9	8	11	4	4	10	1	5	2	10	11	4	8	3	11	10	15	19	10
Eastern	36	12	7	24	27	28	17	19	25	26	26	21	18	17	18	4	8	18	10	15	13	18	13	25	15	14
Eastern	37	6	9	5	7	7	8	10	8	6	5	5	7	5	6	4	5	8	6	9	5	10	6	8	8	6
Southern	1	4	4	7	14	7	8	12	10	11	8	4	7	1	4	6	4	15	11	7	6	12	10	8	8	29
Southern	2	7	6	14	9	18	15	8	6	4	6	6	8	4	2	6	8	8	6	13	6	12	4	11	16	4
Southern	3	7	12	4	4	4	7	7	7	4	4	4	10	5	4	4	9	11	14	5	15	9	6	10	13	8
Southern	4	7	7	10	11	11	8	8	11	7	6	7	8	7	6	7	7	8	9	9	8	10	7	8	10	11
Southern	5	12	4	2	9	20	8	5	10	2	6	11	10	23	16	7	24	14	12	6	8	16	10	15	19	7
Southern	6	10	7	0	6	0	9	6	2	7	7	6	8	3	10	8	7	8	0	6	4	11	13	15	10	13
Southern	7	6	5	8	5	5	4	2	7	3	1	10	7	2	1	0	2	2	1	5	6	8	8	4	7	6

Southern	8	12	6	4	8	6	13	9	6	1	2	2	5	3	4	6	4	11	4	6	7	7	5	8	15	11
Southern	9	9	8	19	9	8	8	6	14	10	5	3	10	5	3	6	2	7	20	15	9	7	9	6	26	18
Southern	10	7	7	11	12	16	8	9	10	4	4	2	4	6	6	6	8	8	8	8	8	9	10	11	13	11
Southern	11	5	6	8	9	4	6	8	19	4	3	4	7	6	0	2	2	3	8	2	6	8	5	15	14	10
Southern	12	6	7	17	16	8	8	11	18	3	3	0	2	4	0	4	7	5	10	8	4	6	18	8	32	24
Southern	13	6	6	4	2	2	6	11	11	4	2	4	6	4	4	2	3	5	5	6	14	11	14	14	12	12
Southern	14	5	7	6	12	12	5	7	11	8	4	6	4	6	3	5	6	7	12	10	10	11	8	9	9	8
Southern	15	5	5	11	9	8	8	11	9	11	5	10	11	9	11	4	2	3	3	10	4	11	17	9	20	13
Southern	16	0	4	21	24	16	8	8	12	0	6	7	12	0	2	2	12	0	15	15	17	15	12	14	9	7
Southern	17	8	7	8	10	5	7	9	10	4	8	8	5	6	4	5	4	4	8	9	8	8	8	9	14	3
Southern	18	4	3	5	6	7	8	4	8	6	5	6	4	3	2	1	5	3	6	6	4	9	11	7	8	8
Southern	19	7	5	20	34	23	9	14	10	2	6	5	12	6	2	3	4	4	5	5	5	9	10	9	20	13
Southern	20	6	7	8	6	5	7	6	11	8	2	2	6	7	15	5	9	2	7	5	5	7	8	8	14	16
Southern	21	7	7	10	11	11	8	9	12	7	0	5	0	1	5	2	1	7	2	8	6	12	4	16	14	9
Intramural	1	5	4	4	20	16	15	7	16	0	1	4	8	7	6	8	4	4	3	5	5	8	13	22	22	14
Intramural	2	8	9	7	6	2	8	0	3	5	2	6	5	5	2	2	7	6	5	8	12	9	12	15	10	11
Intramural	3	4	6	9	11	8	12	10	12	9	10	12	22	13	9	9	7	5	9	8	12	12	10	23	21	10
Intramural	4	6	8	20	8	7	9	7	12	2	8	6	9	10	3	6	6	6	12	15	10	12	10	16	12	12
Intramural	5	13	7	13	13	6	10	17	9	5	4	5	7	10	9	9	11	20	25	23	19	26	16	15	14	14
Intramural	6	6	5	11	13	7	6	17	21	6	10	7	10	2	4	8	7	3	10	7	8	8	10	11	11	12
Intramural	7	4	7	1	10	8	6	9	11	6	0	2	3	2	1	2	3	5	7	4	11	20	7	12	14	15
Intramural	8	6	6	9	13	8	16	20	13	12	5	6	8	8	4	5	8	14	17	10	14	7	10	15	20	9
Intramural	9	7	8	38	33	38	19	41	22	7	7	21	36	6	6	7	7	8	9	4	10	12	20	18	25	17
Intramural	10	0	8	4	3	6	4	8	11	5	13	28	27	13	10	4	11	18	16	9	9	11	17	11	16	10
Intramural	11	10	7	32	38	32	18	16	31	18	13	8	5	4	11	37	36	32	30	24	12	15	15	17	19	19
Intramural	12	7	8	9	11	5	8	11	19	7	3	6	0	1	0	6	3	10	32	6	4	6	7	9	9	15
Intramural	13	7	6	11	12	11	8	8	11	7	4	6	1	4	2	3	9	10	11	9	7	11	10	9	21	22
Intramural	14	4	8	9	4	6	6	7	8	5	2	4	10	3	7	9	4	11	10	10	4	7	8	9	17	14
Intramural	15	7	7	10	11	10	9	9	12	7	6	7	8	7	6	6	8	2	4	2	8	8	8	2	0	2
Intramural	16	6	8	9	2	8	4	1	8	3	2	5	5	0	7	5	5	3	6	7	9	8	8	10	12	3
Intramural	17	7	7	11	11	11	8	8	12	7	7	6	8	6	6	7	7	8	9	9	8	8	9	10	9	8
Intramural	18	9	7	6	4	9	12	9	16	7	6	3	5	8	4	8	7	7	7	14	7	6	6	10	13	14
Intramural	19	7	7	10	12	11	8	9	11	7	6	7	4	7	6	5	10	9	7	8	7	7	8	9	10	9
Intramural	20	7	6	6	7	4	0	0	2	4	10	8	9	17	12	9	7	8	7	6	7	6	7	7	16	15
Intramural	21	8	12	18	8	7	9	11	9	12	11	8	9	10	7	8	5	8	13	8	8	7	9	11	10	11
Intramural	22	10	8	10	11	11	6	7	13	6	4	6	11	16	8	3	4	11	9	9	2	5	13	10	10	11
Intramural	23	9	6	8	4	5	3	4	7	4	2	2	4	4	1	1	0	3	5	5	11	7	7	9	10	10

TABLE 3. DJD severity at the apophyseal joints: Added scores

Burial area	Burial number	C1/2-D	C2/3	C3/4	C4/5	C5/6	C6/7	C7/T1	T1/2	T2/3	T3/4	T4/5	T5/6	T6/7	T7/8	T8/9	T9/10	T10/11	T11/12	T12/L1	L1/2	L2/3	L3/4	L4/5	L3/S1
Eastern	1	18	8	22	19	26	25	7	3	0	6	7	8	8	9	11	12	12	11	8	10	10	10	4	5
Eastern	2	14	17	18	10	9	14	5	2	8	10	7	11	12	16	17	17	12	19	10	9	5	1	6	5
Eastern	3	12	0	4	10	14	14	2	2	4	5	7	6	10	5	11	11	12	11	8	2	4	6	0	4
Eastern	4	8	5	9	5	15	25	5	5	0	0	0	2	2	3	9	6	7	3	2	4	6	12	12	20
Eastern	5	10	1	6	9	0	2	1	0	0	0	1	3	6	8	6	3	2	7	4	4	5	3	2	4
Eastern	6	20	8	14	20	20	18	4	5	13	10	10	9	11	12	8	12	19	16	7	8	6	6	16	15
Eastern	7	2	4	6	0	22	7	0	0	1	1	1	1	1	0	3	1	0	10	5	10	14	34	9	10
Eastern	8	10	7	10	10	0	0	2	0	0	2	4	0	2	3	5	5	3	4	6	4	2	9	9	9
Eastern	9	9	7	10	10	14	0	2	6	4	7	5	7	4	3	4	13	14	17	11	5	4	3	4	6
Eastern	10	10	7	10	10	14	13	5	3	4	6	7	4	9	8	10	16	13	12	7	5	6	6	8	10
Eastern	11	18	11	11	11	31	34	8	8	10	12	18	11	7	11	11	10	14	12	12	16	22	17	19	9
Eastern	12	9	7	10	10	14	14	4	3	4	5	7	8	8	9	12	12	12	11	20	21	24	17	9	16
Eastern	13	18	8	8	11	8	9	10	9	8	8	25	24	28	27	26	32	32	26	10	15	10	8	10	12
Eastern	14	8	10	10	12	12	8	5	16	4	6	7	8	8	9	6	10	12	16	11	14	12	10	9	9
Eastern	15	12	12	16	12	8	32	15	9	11	27	28	49	24	37	49	33	46	25	22	24	20	27	23	19
Eastern	16	8	10	11	7	10	5	16	8	9	15	16	13	14	13	11	11	15	14	9	15	12	13	12	17
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Eastern	22	10	7	10	10	14	13	5	3	4	5	2	8	13	10	26	12	14	10	15	18	31	16	20	10
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Eastern	25	9	7	8	13	22	28	12	8	8	8	10	8	7	10	10	11	8	11	10	16	23	12	15	25
Eastern	26	12	12	21	24	40	39	11	10	7	12	26	9	11	10	13	10	11	6	6	10	10	9	9	9
Eastern	27	4	4	9	10	6	5	0	0	2	5	6	1	1	2	12	1	2	8	1	2	10	13	5	2
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Eastern	30	10	2	5	5	5	13	5	8	0	2	2	9	8	8	11	7	10	13	8	10	7	9	6	9
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Southern	21	10	7	10	10	14	13	4	3	4	5	14	12	19	27	20	24	16	18	17	18	22	27	20	5
Intramural	1	14	6	14	26	26	22	7	8	9	8	4	8	6	7	9	7	9	7	4	5	4	14	17	6
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Intramural	6	8	7	20	21	17	16	0	2	3	8	3	8	8	9	6	12	12	9	5	7	7	13	10	18
Intramural	7	16	4	7	10	27	23	7	2	2	3	11	13	17	15	13	18	20	16	8	19	25	15	0	8
Intramural	8	8	12	10	14	28	4	1	4	6	0	1	13	7	11	12	4	10	5	0	14	20	7	4	12
Intramural	9	26	5	16	8	28	22	7	6	10	8	11	6	9	11	28	26	27	11	11	12	15	18	20	13
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Intramural	11	12	16	16	16	17	25	7	8	8	10	9	6	8	14	13	17	15	17	26	14	7	10	7	14
Intramural	12	14	4	4	4	8	7	0	0	3	2	3	3	1	5	16	16	32	21	6	4	0	5	6	10
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Intramural	14	10	6	3	8	4	2	4	0	1	1	0	1	1	7	5	1	2	17	3	3	0	0	1	11
Intramural	15	10	7	10	10	14	13	5	3	4	5	7	8	8	9	12	12	14	10	3	3	3	1	0	0
Intramural	16	16	6	3	6	5	14	0	0	1	3	7	4	4	6	4	4	4	5	4	6	8	1	5	8
Intramural	17	9	7	10	10	14	13	4	3	4	6	7	8	8	9	11	11	12	11	8	2	8	7	10	8
Intramural	18	8	6	9	13	6	12	3	0	3	7	8	10	15	11	17	19	20	9	8	15	18	11	6	1
Intramural	19	10	7	10	10	14	14	5	4	4	4	5	3	8	6	11	5	5	10	11	8	3	1	2	7
Intramural	20	9	4	6	10	14	13	4	3	8	6	7	8	10	5	16	31	30	17	7	8	8	8	12	12
Intramural	21	6	8	10	13	16	7	4	3	6	2	3	10	9	9	12	14	12	12	8	8	17	9	16	9
Intramural	22	8	8	10	10	10	10	4	0	2	2	3	2	13	4	8	10	11	13	9	6	11	9	0	4
Intramural	23	4	4	0	3	2	4	4	0	0	0	0	2	4	6	14	5	5	5	4	6	5	3	2	0

TABLE 4. Kolmogorov-Smirnov test summary statistics

Joint type	Cemetery area pair	Maximum difference in cumulative proportion	K	Significance (*P*)
Intervertebral	Eastern-southern	0.039	0.14	>0.05
Intervertebral	Eastern-intramural	0.035	0.14	>0.05
Intervertebral	Southern-intramural	0.019	0.07	>0.05
Apophyseal	Eastern-southern	0.037	0.14	>0.05
Apophyseal	Eastern-intramural	0.014	0.05	>0.05
Apophyseal	Southern-intramural	0.032	0.11	>0.05

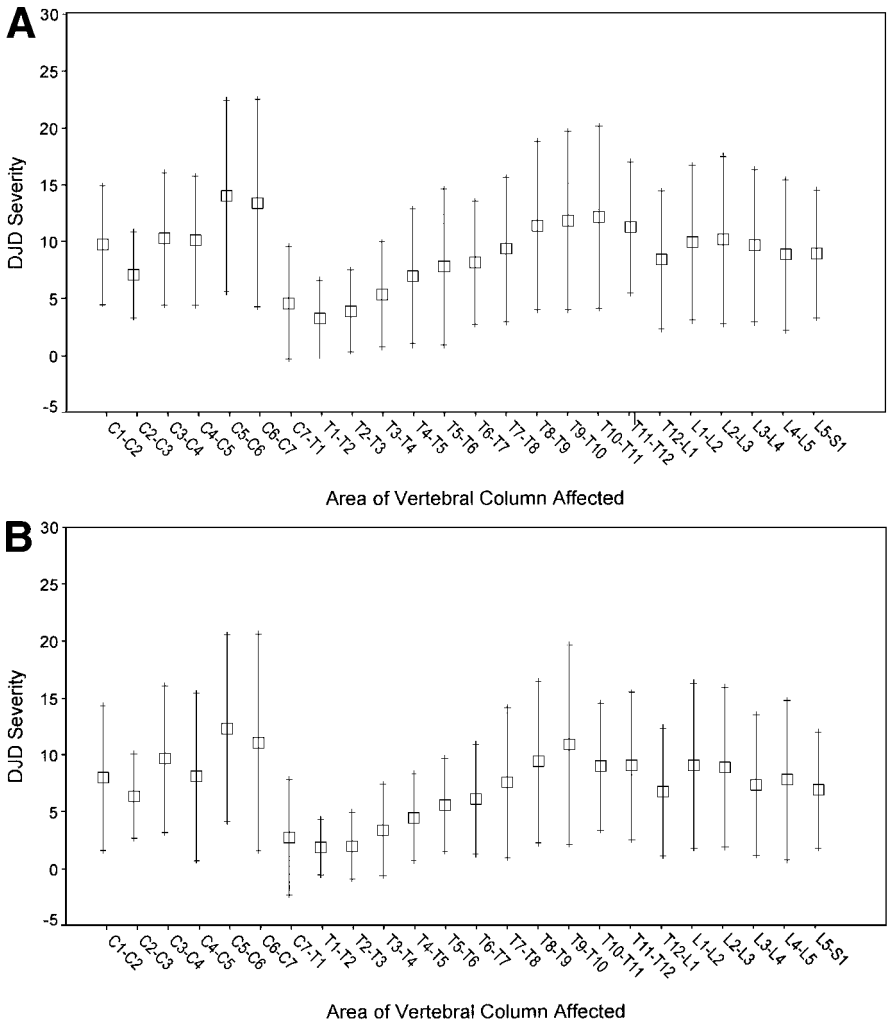
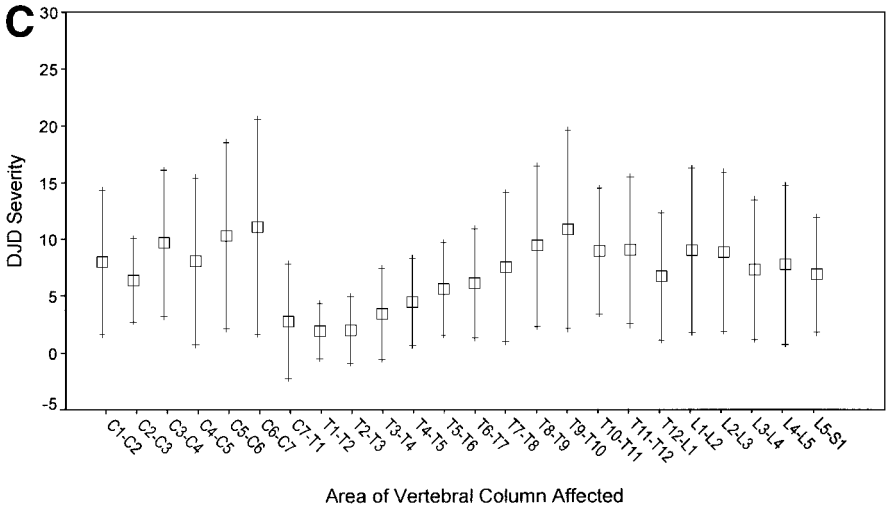
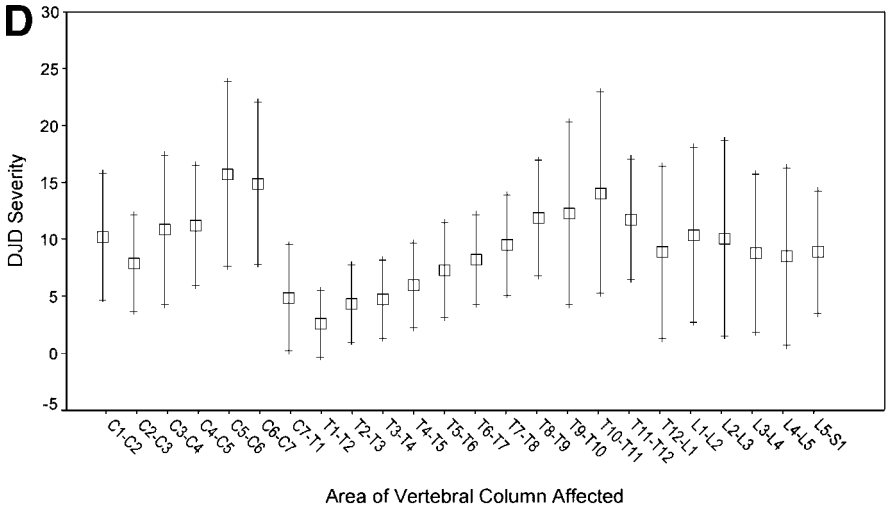


Fig. 1. High-low charts depicting DJD severity and standard deviations (summed scores of all indicators of osteoarthritis throughout). **A:** All intervertebral joints. **B:** Eastern intervertebral joints. **C:** Southern intervertebral joints. **D:** Intramural intervertebral joints. **E:** All apophyseal joints. **F:** Eastern apophyseal joints. **G:** Southern apophyseal joints. **H:** Intramural apophyseal joints.

appeared associated either with EB, with initial fusion and immobility of the joint, or with partial/complete disc ossification. Eburnation was recorded as 1 when less than 50% of the articular surface was affected and as 2 when more than 50% of the articular surface was affected and mechanical scoring and ridging were present.





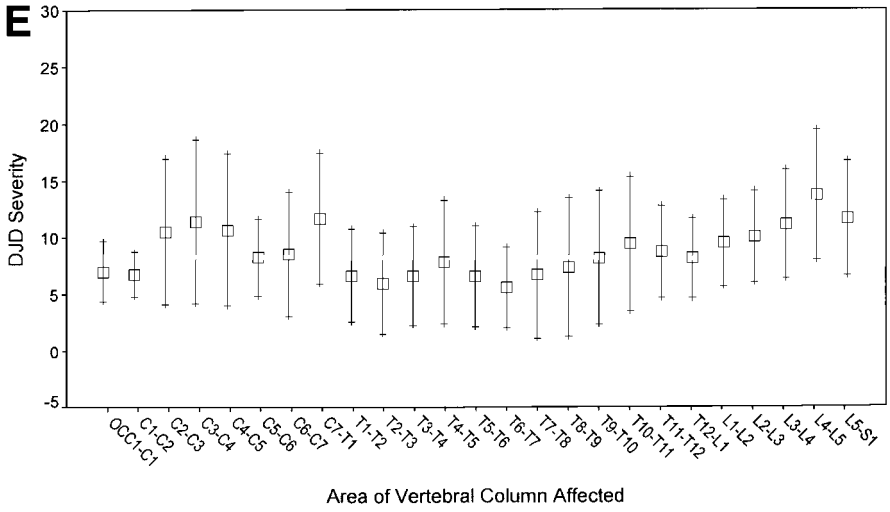


Fig. 1. (*continued*)

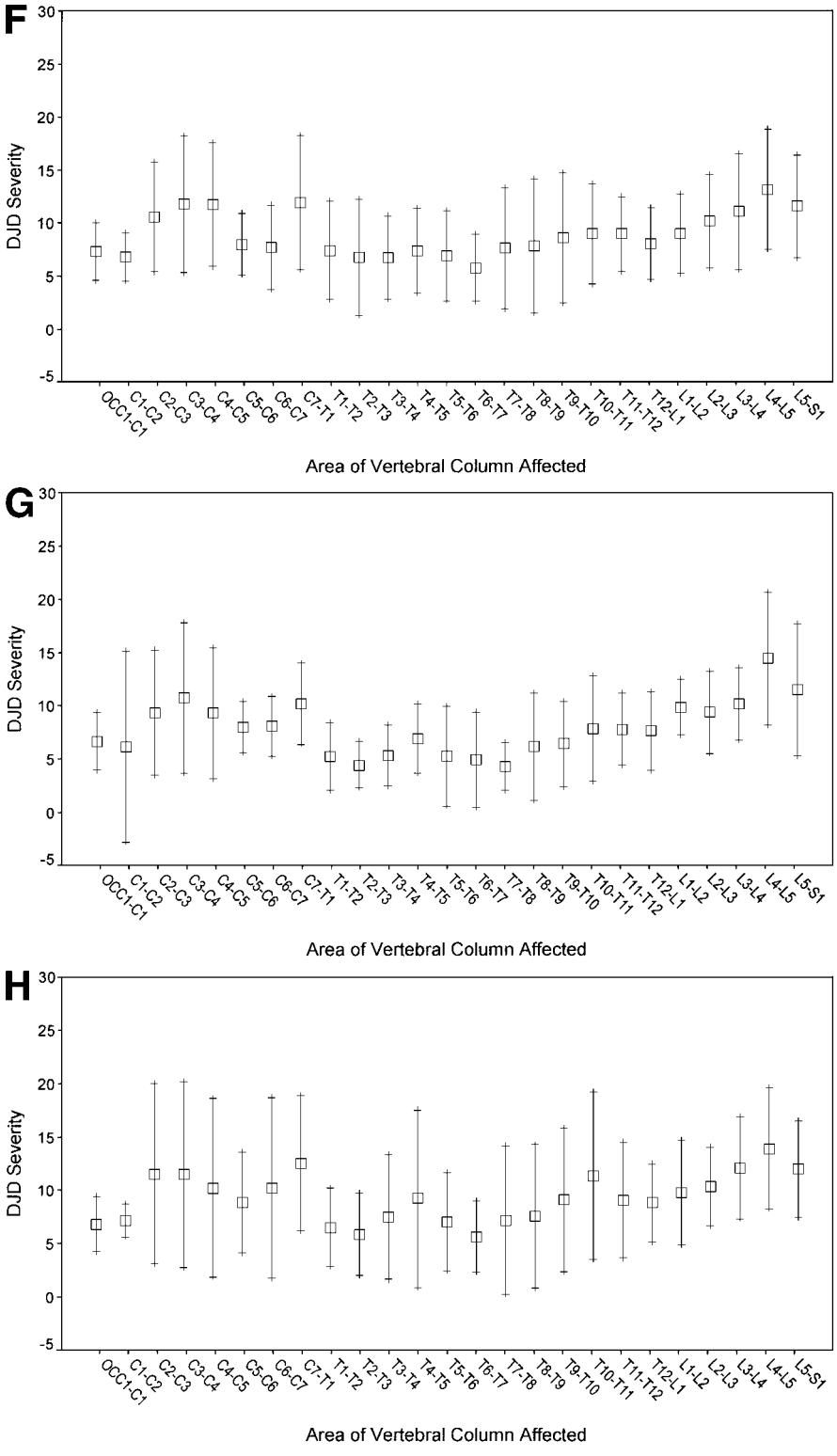


Fig. 1. (*continued*)

TABLE 5. Mahalanobis distance summary statistics

Joint type	Cemetery area pair	Mahalanobis distance	F ratio	Degrees of freedom	Significance	Group centroid function 1	Group centroid function 2
Intervertebral	Eastern-southern	2.68	0.88	24, 33	0.64	0.9090	−0.2980
Intervertebral	Eastern-intramural	2.24	0.80	24, 35	0.73	−1.2290	−0.7380
Intervertebral	Southern-intramural	2.77	0.57	19, 24	0.89	−0.3400	1.1540
Apophyseal	Eastern-southern	2.07	0.68	25, 32	0.85	0.5850	−0.2840
Apophyseal	Eastern-intramural	1.26	0.45	25, 34	0.98	−0.9860	−0.3330
Apophyseal	Southern-intramural	1.70	0.35	25, 18	0.99	−0.0410	−0.7620

An SN achieving a value of 1 was a lesion less than 2 mm deep, covering an area equivalent to less than half the anteroposterior length of the vertebral body. An SN was recorded as 2 when in excess of these values.

Individual lesions, for superior and inferior joint surfaces as well as for right and left apophyses were recorded independently for each joint. A single measure of DJD severity was obtained by summing the lesion scores for each joint, resulting in scores for 49 joints (i.e., 24 intervertebral joints and 25 apophyseal joints) (Tables 2, 3). Missing values due to skeletal incompleteness were created by averaging the existing values for each type of vertebra (cervical, thoracic, or lumbar) for each individual. Averaging the values for the whole vertebral column to replace the missing values was thought to be less accurate, as the three types of vertebrae serve different functions.

To investigate any burial area differences between archaeologically perceivable samples (southern, eastern, and intramural areas), we subjected the summed DJD severity scores to linear discriminant function analysis (SPSS, Inc., Chicago, IL, version 6; method enter), intervertebral and apophyseal joint types being treated separately. Square root transformation of variables with skewness greater than unity was employed to ensure that the distribution of all variables was approximately Gaussian (Lachenbruch, 1975). As linear discriminant analysis is not necessarily particularly sensitive to the actual distribution of DJD severity along the vertebral column, it was decided to test between burial group differences on the basis of a single measure for each joint surface. For each burial area, summed scores for each individual were taken for each joint surface, and the distributions were then compared using the Kolmogorov-Smirnov two-sample test for each pair of burial areas (Table 4). Again, intervertebral and apophyseal joints were treated separately.

Finally, the mean and standard deviation of DJD severity for each joint was plotted for each burial area in the high-low plots depicted in Figure 1. This is merely to give some visual clues to the patterning of DJD along the vertebral column as well as to the variation in severity.

RESULTS

Linear discriminant function analysis on all variables yielded two discriminant functions for both vertebral and apophyseal joints. However, analysis of the group centroids based upon Mahalanobis distance (Kleinbaum and Kupper, 1978), calculated from adjusted regression equivalents (Lachenbruch, 1975), produced no statistically significant differences among burial areas. Summary statistics are presented in Table 5 and plots of discriminant functions in Figure 2A,B. Similarly, Kolmogorov-Smirnov tests between burial groups, based upon total severity for each intervertebral and apophyseal joint, produced no statistically significant differences in severity distribution among burial areas. The overall pattern of DJD along the vertebral column, however, is noteworthy (Figs. 1A–H). This pattern is found across the entire sample. The two types of joints seem to exhibit an almost inverse pattern of severity. Inspection of Figure 1A reveals that the most severely affected intervertebral joints are found at C5 to C6, T8 to T10, and L2 to L3. The least severely affected vertebrae are C7 to T1, T12/L1, and L5/S1. The highest level of osteoarthritis of the apophyseal joints (Fig. 1E) was found at C2 to C4, C7/T1, T10,

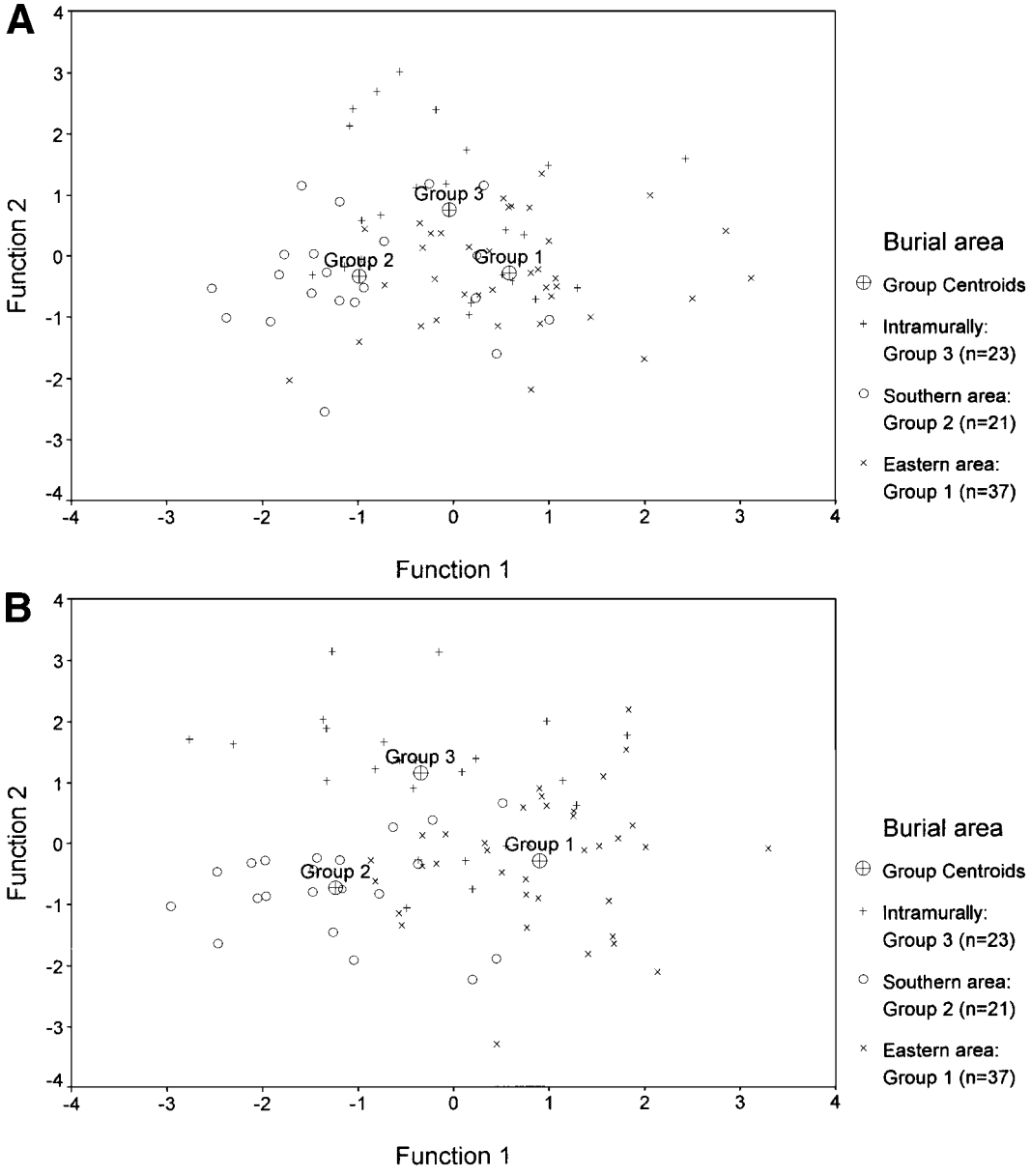


Fig. 2. **A:** Discriminant function for DJD of the intervertebral joints (n = 81). **B:** Discriminant function for DJD of the apophyseal joints (n = 81).

and L3 to L5, whereas the lowest was found in the occipital condyles to C1, C5 to C6, and T1 to T9. Thoracic apophyseal joints demonstrated progressively increasing severity in the lower thoracic and lumbar vertebrae with no distinctive reduction in severity in the L5/S1 segment. These results are consistent with those found by Bridges (1994), Roberts and Manchester (1995), Nathan (1962), and Sager (1969).

DISCUSSION

Contrary to our initial expectations, there was no statistically significant difference in

DJD pattern and severity among the three subpopulations studied. Thus, the statistical analyses conducted do not permit the distinction of those groups previously differentiated on the basis of historical, archaeological, and osteological evidence. As reflected in Figure 1, the pattern of DJD along the vertebral column did not vary among the different burial areas but rather between apophyseal and intervertebral joints, reflecting normal vertebral curvatures.

The vertebral column is the central structure of the human axial skeleton. It connects the axial and appendicular skeletons through the shoulder girdle and the *os coxae* and is affected by the movements of all the elements of the appendicular skeleton as well as by breathing motions. Among its basic functions is the support it provides for upright posture and bipedal locomotion (Krogman, 1951; Napier, 1967) and the transmission of body weight to the lower limbs. Thus, the vertebral column must balance movement with support, flexibility with fixation. The spinal muscles and the powerful ligaments that bind the vertebral column aid in maintaining the balance between fixation and flexibility. The complexity of the balance between movement and support of the vertebral column also requires that its parts (cervical, thoracic, lumbar, and sacral) differ in function. Moreover, the weight borne by the vertebral column increases progressively from the cervical to the lumbar regions. In addition, the greater thickness of the intervertebral discs in the cervical and lumbar regions as compared to the upper thoracic region is associated with the greater individual ranges of movement occurring in those regions (Williams and Warwick, 1980).

The two types of joints present in the vertebral column reflect this balance between support and movement: the intervertebral joints allow a minimum of movement and provide support, whereas the apophyseal joints provide less support with varying degrees of movement depending on the region of the vertebral column. This functional difference is reflected in the inverse pattern of DJD between apophyseal and intervertebral joints, as demonstrated in the high low plots (Fig. 1A,E). The C7/T1 joint, for example, shows the lowest severity of DJD of the intervertebral joints and among the highest severity of DJD of the apophyseal joints, being an extremely stressed area in movement. In this area the vertebral column changes from primarily weight-bearing to increased rotation and from anterior to posterior curvature. It is also in this area that the upper girdle and vertebral column are linked.

Through remodelling of its constituent elements, the skeleton adapts to applied stresses and maintains its integrity in support and movement (DeRousseau, 1988; Rubin et al., 1990). The pattern of DJD of the apophyseal joints seems to reflect the stresses produced in the vertebral column by movements through reducing or accentuating the vertebral curvatures, whereas the pattern of intervertebral severity reflects the vertebral curvatures, showing highest severity where the curvatures are farthest away from the line of gravity and lowest where the vertebral column passes through it.

Thus, the DJD severity pattern along the vertebral columns of the individuals of the sample studied appears to be due to biological factors rather than any potential activity-related or social differences. It is advisable, therefore, not only to be skeptical about the use of DJD patterning and severity for activity-related osseous studies but also to concentrate on skeletal structures not directly involved in normal locomotion and upright posture when studying activity-related osseous changes.

CONCLUSIONS

The quantitative statistical evaluation of the DJD severity data for each skeleton and for each burial area did not offer results of acceptable statistical significance to support the predicted distribution that was expected to exist among the three cemetery areas. Further, the high-low charts (as presented in Fig. 1) showing the pattern and severity of DJD along the vertebral column demonstrate no difference among the three cemetery areas but a striking difference between the patterns of intervertebral and apophyseal joint DJD severity due, it seems, to the functional differences between the two types of joints and the different stresses these place on them.

In the light of the results obtained from this study, two conclusions can be drawn. In the first place, the present study contributes to the current perspective that DJD is not a suitable way to study normal activity-related osseous change. Further, the vertebral column might not be an ideal structure to study activity-related osseous alteration because biological constraints obscure the expression of occupational markers of stress. In order to demonstrate increased severity due to activity, it seems that the forces must be of considerable magnitude, like those postulated by Lovell (1994) to exist in the cervical vertebrae of ancient Harappans, likely in response to repeatedly using their heads for weight-bearing activities (for Inuit activities see Merbs, 1983). As others have suggested in the past (Bridges, 1994; Jurmain, 1977; Ortner 1968), the upper limbs and pectoral girdle are proposed as more suitable structures to assess activity-related differences between human populations or subpopulations, as they are normally exempt from weight-bearing, locomotion, and postural support.

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